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REARFOOT KINEMATICS IN DISTANCE RUNNERS: ASSOCIATION WITH OVERUSE INJURIES

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Distance runners suffer often from overuse injures, caused by excessive pronation or supinating foot. The purpose of this study was to compare the rearfoot kinematics and the questionnaire results of incidences of overuse injuries symptoms. Fourteen distance runners, who were distributed into the more-symptomatic (MSL, n = 7) and less-symptomatic (LSL, n = 7) groups according to the questionnaire participated in this study. The subjects ran at average speed 3.79 $m \cdot s^{-1}$ on the 5,8 m runway with four markers set on rearfoot and shank, and kinematics were determined using the motion analysis system with 6 and 8 cameras. For the rearfoot kinematics analysis the angles between calcaneus and shank in both legs were measured: angle at impact; maximum angle; the pronation amplitude; time from impact to maximum angle; time from maximum angle to toe-off supination. The pronation amplitude in the right foot was greater ($p < 0.05$) in MSL compared to LSL group (5.5º and 8.2º, respectively; $p = 0.02$). The other measured parameters did not differ significantly between the groups. We concluded that the variations in rearfoot kinematics can not be the reasons for causing the symptoms of overuse and their origin should be searched from training errors.

Key words: rearfoot kinematics, running, overuse injures

INTRODUCTION

Running is one of the most popular forms of physical activity. Unfortunately the yearly incidence of injuries among runners is estimated to be between 37% and 56%, 70–80% of these injuries are of an overuse type and involve the knee, leg, ankle and foot [15]. Training errors are the predominant factor in producing runner's injuries, followed by anatomic factors, running shoes and surfaces. Anatomic factors generally involve abnormal biomechanics or malalignments of the lower extremities [6]. It has been affirmed that females are more predisposed for overuse injuries, but several research showing no differences between sexes [10, 8]. Runners with excessive or compensatory pronation of the foot are especially predisposed to injuries. Compensatory pronation with increased internal *tibia* rotation places additional stress upon the foot, ankle, knee, hip and lower back. More rigid foot represents a poor shock-absorbing mechanism due to inadequate foot flexibility to dissipate forces [14]. Supination and pronation are the movements of subtalar joint. With the help of rearfoot kinematics during running it is possible to indirectly calculate the movement of pronation/supination of the subtalar joint.

The human shank and foot complex is an intricate multi-joint mechanism fundamental for the interaction between lower limb and ground during locomotion. A most realistic relevant representation would involve a large number of anatomical landmarks, a robust and flexible technique for spatial registration together with a software tool for data organization [2]. There are many different methods and models for clinical and scientific use to measure foot kinematics [1, 18].

The aim of this study was to compare rearfoot movement during stance phase and the incidence of the symptoms of running-induced overuse injuries in the more-symptomatic (MSL) and less-symptomatic (LSL) subjects group. Therefore, we investigated with the four-marker indirect method [5, 7, 14, 16] the movement of the subtalar joint and tested the hypothesis that overpronative or too rigid foot can be the cause for more overuse injuries.

MATERIAL AND METHODS

Subjects

Fourteen distance runners (10 male and 4 female) around Bologna (Italy) participated in this study (trainings per week 6.9 ± 1.3 h; running kilometers per week 90 ± 40.2 km). The subjects were distributed into more-symptomatic (MSL) and less-symptomatic (LSL) groups by questionnaire. Their age and anthropometric characteristics are presented in Table 1. The subjects were screened by a questionnaire to determine their lower leg overuse injuries. The subjects who scored 21 or more of 33 were defined as MSL and those who scored 21 or less of 33 were defined as LSL. All the subjects were informed of the procedures to be utilized as well as the purpose of the study and their written informed consent for participation was obtained. Prior to testing, each subject read and signed an informed consent document approved by the University of Bologna.

Table 1. Age and anthropometric characteristics of the subjects (mean±SD)

		MSL (n=7)	**LSL (n=7)**
Age (years)		26.0±7.1	28.0±6.8
Height (cm)		173.0±8.0	169.9±11.9
Body mass (kg)		62.4±7.2	61.1±6.6
Body mass index (kg·m^{-2})		20.7±1.5	21.2±0.5
Trainings per week (h)		6.7±1.7	7.0±1.0
Running per week (km)		85.7±26.2	100.0±49.1
Knee circumference (cm)	**Left**	36.2±1.9	34.8±1.8
	Right	36.2±1.9	34.9±1.5
Ankle circumference (cm)	**Left**	25.0±1.7	24.3±1.5
	Right	25.2±1.4	24.4±1.4
Leg Lenght (cm)	**Left**	92.7±6.4	89.7±5.6
	Right	92.9±6.5	89.0±5.6

Notes: MSL – more symptomatic group (1 woman; 6 men); LSL – less symptomatic group (3 women; 4 men)

Assessment and Experimental protocol

The tests were carried out in the Movement Analysis Laboratory, Rizzoli Ortopaedic Institute, (Bologna, Italy) and in the Biomechanical Laboratory at the University of Bologna (Italy). The used equipment stereophotogrammetric system Vicon 612 (Vicon Motion Capture, Oxford UK) for human movement analysis with 8 television cameras M2 and 2 force plates (Kistler, Switzerland) at the frequency of registration 100 Hz, at Rizzoli Institute and Vicon 360 with 6 television cameras, 200 Hz in the Biomechanical Laboratory at the University of Bologna. Four spherical markers of 9-mm diameter were used: (1) the most prominent posterior part of *calcaneus*; (2) 3 cm upward from the first; (3) 8 cm upward from the second; (4) 8 cm upward from the third. The cameras were positioned to obtain a rear (frontal plan) view of the shank and *calcaneus* during the stance period. The subjects were running on the 5.8 m runway with the average speed of 3.79 m/s. A force platform was embedded in the middle of the runway, where the subjects had to step six times with the left and six times with the right leg. The data was calculated using Vicon Workstation Ver. 4.1. The angle between rearfoot and shank was found on the graph and subtracted from 180º.

During the anthropometrical measurements, the subjects lay on the therapeutic table. The circumferences of the knee, ankle and the length of the leg from *spina iliaca anterior posterior* to medial malleolus were measured. Four markers were fastened on the *calcaneus* and shank when the subject was standing on the platform with feet apart 10 cm. Before the experimental procedure, the subjects were acquainted with the laboratory and the 10-m running track, which included 5.8 m runway with a force platform. They performed barefoot running trials to determine their starting positions, self-selected speed and their preferred cadence. They were instructed to step on the force platform by left or right leg, six times each. The ground reaction force and shank and *calcaneus* kinematics data were collected during 12 running trials.

From the coordinates the following angles were calculated (Figure 1): (1) impact angle; (2) maximal rearfoot angle; (3) pronation amplitude; (4) the time from impact to maximum pronation; (5) the duration of pronation.

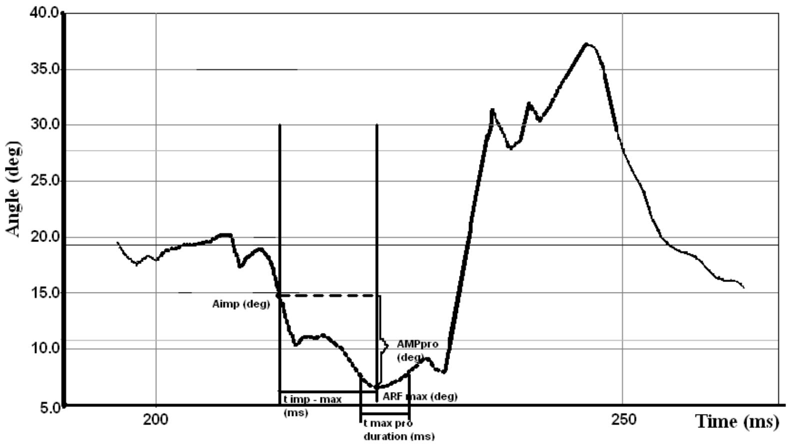


Figure 1. Representative rearfoot angle versus time curve for stance phase. Aimp – impact rearfoot angle; t imp − max – time from impact to maximum rearfoot angle; t max pro duration – duration of the maximum pronation; ARF max – maximum rearfoot angle; AMPpro – amplitude of pronation.

Statistical analysis

Date are expressed as means and standard deviation (±SD). An one-factor ANOVA with the Tukey post-hoc test was used to compare anthropometric parameters between groups. A level of $p < 0.05$ indicated statistical significance.

RESULTS

The rearfoot impact angle and the maximum angle did not differ between the two measured groups (Fig. 2). The amplitude of right foot pronation was greater ($p < 0.05$) in LSL than MSL group (8.2º and 5.5º respectively, $p \leq 0.02$). There were no significant differences in the pronation amplitude of the left foot between the groups (Fig. 2).

The time parameters (the time from impact to maximum pronation and the duration of maximal pronation) did not show any significant differences between two groups (Fig. 3).

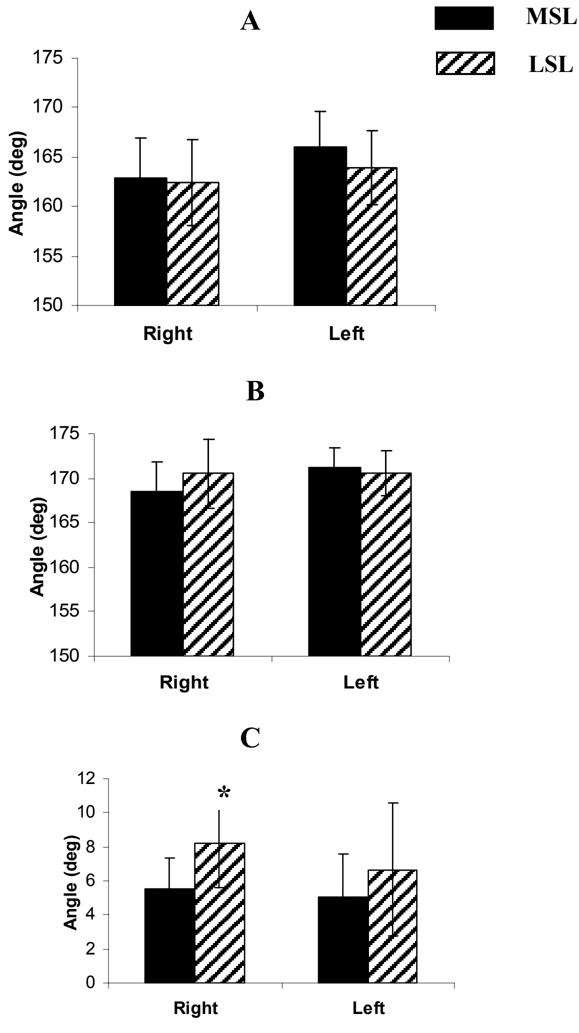


Figure 2. The angle between the shank and rearfoot in impact (A), the maximum angle between the shank and rearfoot (B) and the amplitude of pronation (C) in the right and left foot more (MSL) and less (LSL) symptomatic groups (mean±SD).* $p \leq 0.05$.

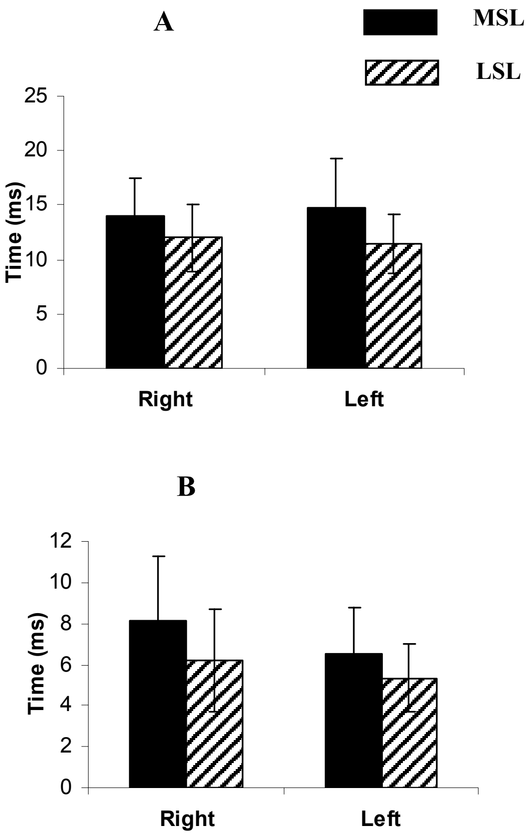
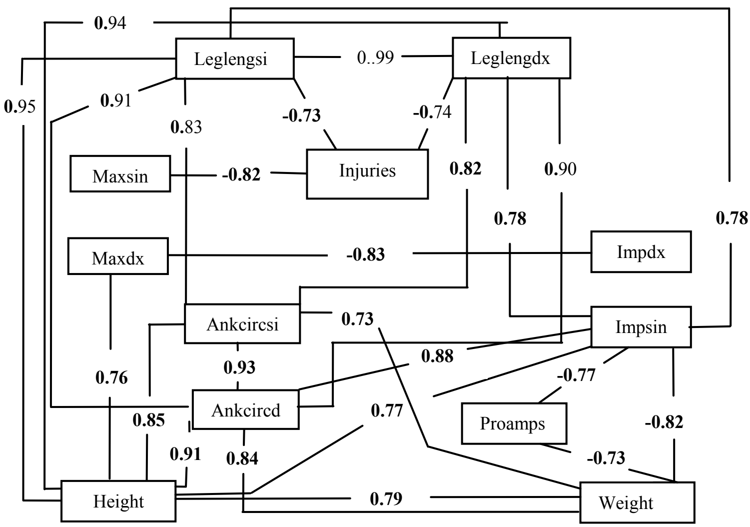


Figure 3. The time from impact angle to maximal pronation (A) and the duration of maximal pronation (B) in the right and left foot more (MSL) and less (LSL) symptomatic groups (mean±SD).

Figure 4 demonstrates significant correlations between the measured characteristics in MSL group A and LSL group B. In the MSL group, the injuries correlated negatively with the length of the right ($r = -0.74$; $p < 0.05$) and left leg ($r = -0.73$; $p < 0.05$) and with the maximal rearfoot angle in the left foot ($r = -0.82$; $p < 0.05$). Also the impact angle in the left foot correlated negatively with the amplitude of pronation in the MSL group (r = –0.77; p < 0.05). The weight correlated negatively in the MSL group with the left foot impact angle (r = –0.82; p < 0.05) and the pronation amplitude (r = –0.73; p < 0.05).

In the LSL group, the body mass index (BMI) correlated negatively with the time from the impact to the maximum pronation in the left leg (r = –0.74; p < 0.05).

A



B

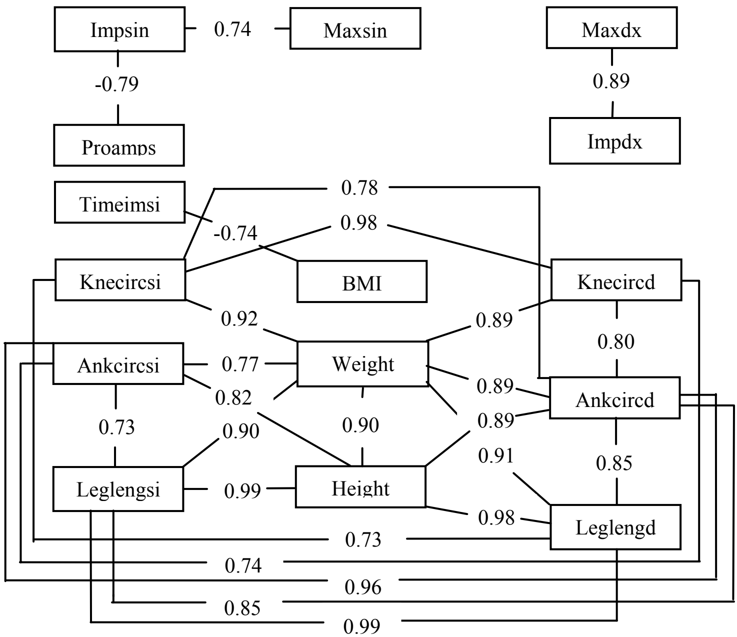


Figure 4. Significant correlation coefficients between the mean variables in more (A) and less (B) sympomatic groups.

Leglengsi – lenght of the left leg; Leglengdx – lenght of the right leg; Maxsin – the maximal left shank-rearfoot angle; Maxdx – the maximal right shank-rearfoot angle; Impdx – right shank-rearfoot angle at impact; Impsin – left shank-rearfoot angle at impact; Ankcircsi – left ankle circumferance; Ankcircd – right ankle circumferance; Proamps – the left pronation amplitude; Timeimsin – the time from left leg impact to the maximum pronation; Knecircsi – the circumference of left knee; Knecircd – the circumference of right knee; BMI – body mass index.

DISCUSSION

This study indicated that during barefoot running with no previous fatigue did not emerge any differences in the rearfoot and shank movement angles that could be causing more overuse injuries symptoms for distance runners. The pronation amplitude in the right foot in the LSL group was significantly greater compared to MSL group. In the LSL group right foot pronation was 32.7% greater than in MSL group (LSL 8.2° vs. MSL 5.5°). Also the pronation in the left foot in LSL group was greater than MSL group by 23.65%, but the difference was not significant. The interchange between pronation and supination is necessary for a normal gait. The problems arise with excessive or prolonged pronation during the support phase [6]. The LSL group showed even faster times from impact angle to maximum pronation for both feet. However, the differences were not statistically significant. It can be speculated that MSL group indicated too slow changes from impact supination to stance phase pronation, due to this increased forces were applied to the supporting structures of the foot and leg. The additional effort will be required of the intrinsic and extrinsic muscles in order to stabilize the foot during push-off [6]. There were no indicators in the current study to prove that the subjects in the MSL group suffer more with right side injuries. However, the results agree with other studies [5]. The time parameters were equally shorter in the LSL compared to MSL group and the differences between the right and the left leg were not significant. The differences were symmetrical.

The tendency for a runner to become injured on a particular side may be related to lower extremity asymmetry [17]. In the present study, we did not find any statistically significant differences either in ankle and knee circumferences or the length of the legs between two groups. It is interesting to note that the overuse injuries symptoms were negatively correlated only in the MSL group with the length of both legs and the maximum pronation angle in the left leg. The leg length can change the location of the center of gravity. Perttunen et al. [12] found in their study during walking that the shorter limb bore the weight for less time than the longer limb and the pressure was higher in the push-off phase on the longer limb. It is important to notice that the differences increased at faster walking and would probably increase even more with running. The hypothesis can be made that during the running with increasing speed even the smallest differences could be significant for the development of injuries over prolonged time. The negative correlation between left leg maximum pronation and injuries indicate that the rigid supinated foot more overuse injury symptoms. The MSL group showed positive correlation between right ankle circumference and left leg impact angle. It can indicate that the right leg could be more dominant. Body mass correlated positively with the left and right ankle circumferences in MSL and LSL groups, but the correlation was greater on the right ankle in both groups. Pronation amplitude differed significantly between MSL and LSL groups and correlated negatively with body mass in the MSL group. The increased body mass probably requires greater pronation to cushion. But neither the BMI nor body mass correlate with injuries. This result is controversial to other study, where the BMI was the most significant parameter to cause the risk of the medial tibial stress syndrome, one of the most common overuse injuries [13]. The BMI had a negative correlation in the left foot with the time from impact to maximum pronation in LSL group. Interestingly, the body mass correlated only with the anthropometric parameters in LSL group. In MSL group the body mass correlated with the left leg pronation amplitude and impact angle.

Davis and Dierks [3] found that the coupling between the rearfoot eversion and knee flexion did not differ between patellofemoral pain syndrome group and the controls, but both groups increased their coupling angles over the course of the prolonged run. There are more evidences that indicate the influence of fatigue to the appearance of overuse injures [9]. It seems that the fatigue and, as mentioned earlier, training errors are the first origin for overuse injures [11]. It seems that the 90-min running was not enough for exhausting [4], but the accumulation of impact loading overtime [6, 5]. We can conclude that decreased pronation amplitude can be the cause for higher in incidence of the overuse injuries symptoms in MSL compared to LSL group. However, due to major differences between the research results, it is still more likely that training errors and the non-individual approach to the runner during the training planning process cause more risk for overuse injuries.

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